Power Developed by an Hydraulic Ram

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Hydraulic Ram

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POWER DEVELOPED BY AN HYDRAULIC RAM

A THESIS

PRESENTED BY

W. L. BROCK
P. J. SCOTT

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

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-: INDICATED POWER OF AN HYDRAULIC RAM :-

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B.& S.

-: SUBJECT :-

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-: INDICATED POWER OF AN HYDRAULIC RAM :-

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B.& S.

-: INDICATED POWER OF AN HYDRAULIC RAM :-

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OBJECT:-

The object of this Thesis investigation was to ascertain whether the power developed by an hydraulic ram could be determined by means of an indicator.

DEFINITION:-

The hydraulic ram is a device which receives a certain amount of water under a certain head and elevates a portion of this or other water to a greater head. When the water pumped is a portion of that supplied the ram is said to be single acting. When the water pumped is taken from some source other than that of the water supplied to operate the ram, it is said to be doubleacting. What follows will apply only to single acting rams.

ACTION:-

The action of an hydraulic ram is as follows; (See Fig. Ia, Plate I). Water enters the ram through the drive pipe E, sometimes called the supply pipe. It escapes through the waste valve B, also called the clack valve. When the water has acquired a sufficient velocity, the friction of the clack valve causes it to close. The water in the supply pipe having acquired considerable momentum, forces the clack valve Q open, and forces a portion of the water into the air chamber C, and out through the discharge pipe F. The air chamber is necessary in order to avoid the severe effects of water hammer, which otherwise would take place. When all the dynamic

energy of the water in the drive pipe has been used up in pumping a portion of the water against the discharge pressure, the pressure in the air chamber tends to force the water back through the check valve. This check valve closes but not until the water in the drive pipe has acquired a slight reverse motion. This reverse motion causes a reduction in pressure beneath the clack valve causing it to open. If the clack valve opens slowly a vacuum is produced beneath it. As soon as the reverse motion of the water, in the drive pipe, has been stopped by the force of gravity, the water again flows downward and through the clack valve. This series of operations may be called the cycle of the ram. The rate at which these operations are performed depends upon the supply head; discharge head; the size, shape, and inclination of the drive pipe; and on the character and adjustment of the ram.

As a rule considerable difficulty is met with in the operation of hydraulic rams in keeping sufficient air in the air chamber. The water leaving the air chamber absorbs a considerable amount of air, thus gradually removing it all unless constantly replenished. In the Deming rams provision is made for automatically injecting a small amount of air into the air chamber each stroke. This is accomplished as follows.

When the clack valve is opened by the rush of water up the drive pipe, a small amount of air is drawn in. This air collects beneath the check valve at Q, (Fig. I, Plate I), and

is forced into the air chamber when the clack valve closes again. When the ram is pumping against heads of twenty pounds or more, a large vacuum is produced in the ram at the instant the clack valve opens. A very large amount of air is thus drawn into the ram. The result is that, sometimes, the ram pumps air for the most part, and very little water, at high pressures.

FIRST APPLICATION OF INDICATOR:-

As far as the writers know, the indicator was first applied to an hydraulic ram at the Pennsylvania University. The indicator was attached to the ram below the clack valve and was also attached to the drive pipe near the supply tank. Only a few cards were taken as they were not thought to show much of interest. The indicator drum was rotated at a constant speed by means of a chronograph, so that the time of the various events could be determined.

APPLICATION OF TUNING FORK IN TIMING THE EVENTS OF THE STROKE:

In the present investigation the method of obtaining the time of the various events, from the cards, was that devised by Instructor Arthur H. Anderson, of the Armour Institute of Technology. This method consists in allowing a pencil, attached to a tuning fork, to trace a curve upon the same card as , and simultaneous with the curve traced by the indicator.

CONDITIONS:-

A number I2 Hydraeram, made by the Deming Company of Salem, Ohio, was used in this investigation. The water was supplied through an inclined pipe, 49 Ft. 7 In. long, and making an angle of 6-2/3 degres with the horizontal. The water was supplied from a constant head of 6.I feet. The globe valve in the supply pipe was full open during all the runs. The discharge pressure was varied for different runs. For variation in discharge pressures see tables.

ARRANGEMENT OF APPARATUS:-

The arrangement of the apparatus as used in connection with this Thesis investigation is well shown in the accompanying photographs and blue prints.

The supply tank is located in one extreme end of the Hydraulic Laboratory. The water is supplied the ram through a I-I/2-inch pipe, taking water from four inches below the water level in the reservoir or supply tank. The reservoir receives its supply from the city main. The water level is maintained constant, in the reservoir, by allowing an excess of water to enter the tank, from the city main, thus insuring at all times a flow through the overflow discharge pipes near the top of the reservoir. There is but one bend in the supply pipe, and that is a right angle bend near the enterance to the ram. The supply pipe is provided with a single globe valve for cutting off the supply, and this is located as shown in the photograph 5 page 7.

The water that escapes through the clack or waste valve is caught in a suitable inclosure surrounding the ram, and is discharged through an one-inch pipe into either of two weighing tanks resting upon platform scales. The waste water may be discharged into either of the two tanks by manipulating the three-way valve as shown in photograph 2 , page I. The waste valve is weighted and the amount of opening, or in other words, the length of the stroke is regulated by a nut upon the valve stem. (See photograph 8, page 6). The discharge pipe is connected to the air chamber as shown in the photograph 8 , page 6 . By means of a three-way valve, the water may be discharged into either of two pails; photograph 6, page 8 . The discharge pressure, or head, is regulated by a valve X', photograph 3 , page 3, located as shown in the photograph in the discharge pipe. The discharge pressure in pounds per square inch is obtained by observing the position of the mercury column in the pressure gauge G, as shown in photograph page 3 . The gauge is placed between the ram and the pressure regulating valve. In obtaining the true discharge pressure, due allowance was made for the position of the gauge with respect to the datum plane. The datum plane above which all pressures, or heads, were reckoned was taken as a horizontal plane passing through the center of the supply pipe as it enters the ram.

A Fairbank's 2000 pound platform scales, graduated to

read in one-half pounds, was used for weighing the waste water A small 100-pound scales, graduated to read to one hundreth of a pound, was used for weighing the water pumped. A view of the small scales is given in photograph 6 , page 8 ; and a view of the large scales appears in photograph 3 , page 3 .

MEASURE OF THE VARIABLE PRESSURE IN THE RAM:-

Inorder to obtain a measure of the variable pressure in the ram, and acting on the clack valve B,(Fig. I, plate I), an indicator was attached as shown in photograph I , page 2 .

A Calkins steam indicator was used. A thirty pound spring was used throughout the test. It was necessary to dispense with the ordinary drum, used for steam engine work, and provide a drum capable of being continuously rotated in either direction. For this purpose a special drum, three inches in diameter and four and one-half inches in length, was made. To rotate the drum continuously an one tenth horse power, G. E., shunt wound motor was used. The normal rating of this motor was 2000 R.P.M., but in order to obtain the desired speed at the drum a serier of reducing pulleys were interposed between the motor and the ram, giving a reduction of one to thirty. Two rheostats were placed in series with the armature winding, by means of which the speed of the motor could be reduced to 6000 R.P.M. By means of the rheostats very fine regulation in speed could be obtained. The low speed was desired in order that diagrams of two consecutive

strokes might be traced upon the same card, while the drum made one revolution. A groove was cut in the lower portion of the drum to receive a belt from the reducing pulley.

In order to determine the time between successive strokes and various events , given on the indicator card, provision was made for a tuning fork, electrically vibrated, and suitably mounted, to trace a curve upon the same paper as, and simultaneous with the pencil of the indicator. The tuning fork was so mounted that the movement of both fork and indicator motions were in the same vertical plane; and the pencil points were in the same vertical line. By this construction the indicator diagram would be corrected for any variation in the speed of the indicator drum. For a view of the tuning fork, indicator, and motor, see photograph I , page 2 .

CLACK VALVE PENCIL MOTION:-

In order to determine the action of the clack valve, with reference to the indicator card, a pencil motion was constructed, by means of which the motion of the clack valve was transmitted to an arm carrying a pencil. This pencil also traced in the same vertical line as the tuning fork and indicator. The pencil motion was attached to the clack valve as shown in photograph 8 , page 6 . Errors due to lost motion were guarded against by attaching a spring to the pencil arm as shown in photograph I , page 2 .

OPERATION:-

The operation of the ram was as follows. The reservoir, or supplu tank, was allowed to fill from the city main so that it was overflowing through the overflow, the valve in the supply pipe was then opened and the water allowed to enter the ram.

Two series of runs were made. The first series of runs was made with valve openings of; one-half, one, two, three, and four turns. For each valve opening a set of runs was made. Begining with as low a discharge pressure as would operate the ram, and increasing by increments of two pounds, for each run, until the limiting discharge pressure, at which the ram would deliver water, was reached.

In the operation of the ram the air accumulated so rapidly as to cause the water level, in the air chamber, to fall below the discharge pipe. In this case a quantity of air would pass out the discharge pipe, and the pressure would fluctuate so greatly as to make it impossible to make a satisfactory run.

In order to provide a separate escape for the accumulating air, an air cock was provided and attached to the top of the air chamber, as shown in photograph 5 , page 7 . That the water level in the air chamber of the ram might be kept constant, or at least be at the same level at the end as at the begining of each run, it was necessary to provide a gauge glass. Accordingly a water glass was attached to the air

chamber, as shown in photograph 4 , page 4 . With the addition of both air cock and gauge glass a second series of runs was made; with valve openings of one, two, and three turns.

Beginning with a discharge pressure of five pounds for each set, the pressure was increased for successive runs by five pound increments. With air cock and gauge glass it was possible to so regulate the escape of air that the water level remained constant throughout a run. It was impossible to make runs at high discharge pressures, however, because the ram ceased to pump a satisfactory amount of water, although with the discharge valve completly closed and the clack valve open four turns a pressure of thirty two pounds could be obtained, still the ram would not satisfactorily discharge water for the same valve opening against a pressure of twenty pounds due to the accumulation of air. With a discharge pressure of twenty five pounds, the air accumulated so rapidly that it was impossible to relieve it without effecting the water level in the ram. It was on this account that the results, or data, obtained in series number one were rejected.

The water discharged through the waste or clack valve was collected and weighed in a box tank resting upon platform scales. The water pumped was discharged into either of two pails and weighed upon a small 100-pound Fairbank's scales. The gauge used on the discharge pipe was a Tagliabeue mercury column pressure gauge reading to thirty one pounds, and cali-

brated to read in one-half pounds. During each run of both series four good cards were obtained. Two of these were taken with the drum rotating at such a rate that it was possible to trace a complete cycle of operations upon the same card. Two of these were also taken with a faster speed in order to more clearly bring out the changes occuring while the clack valve was open. The cards used were four by ten and one-half inches. The cards were wrapped around the drum and held in place by two rubber bands one at either end. The motor was closed down while placing cards upon the drum, and also while removing them. The arrangement was such that the tuning fork traced a curve at the top of the card, the indicator at the bottom, while the clack valve pencil motion traced a curve between the tuning fork and the indicator.

In taking cards the three pencil motions were simultaneously pressed against the rotating drum. A blue print of one of the cards obtained is herein shown. For a view of the arrangement of the tuning fork, indicator, and clack valve motion, see photograph I , page 2 . The tuning fork was electrically vibrated. The runs were each of fifteen minutes duration. During each run close watch was kept on the supply head to make sure that the head remained constant. The position of the weight on the clack valve was the same for all runs.

CALIBRATIONS:-

The scales used for weighing the water wasted, and those used for weighing the water pumped, were calibrated with standard weights, before and after the experiment.

The scales used for weighing the waste water were balanced with the empty weighing tank. Fifty pound weights were then added up to six hundred pounds, the scales being balanced after the addition of each weight. The scales were found to very accurate, being correct to within one-half pound in six hundred. The sensibility of the scales was found by noting the weight which had to be added to disturb their balance. This was found to be less than one-fourth pound, for all loads. No corrections were made, therefore, to the weights obtained by these scales.

The scales used for weighing the discharge water were calibrated in a similar manner and found to be correct. They were sensible to the hundreth of a pound at all loads.

The indicator spring was calibrated by attaching the indicator to the air chamber at D, (Plate 4). The pressure was increased by two pound increments up to twenty four pounds, and then decreased by the same amounts. At each pressure a line was drawn on the card. The true ordinate for each pressure was assumed to be the mean between the two thus obtained for each pressure. The scale of the spring was found to be fairly uniform, varying from 26.5 to 27.0 pounds per inch.

The friction of the indicator was constant. But the erroe due to friction and lost motion was rather excessive, being about three -fourths pounds.

The tuning fork was calibrated against a standard fork whose frequency was one hundred. The period of the fork was found to be 0.0298 seconds.

The planimeter used was calibrated and found to read one-half percent too high.

CORRECTIONS:-

Due to the fact that the indicator and gauge were located at some distance above the datum plane it was necessary to apply several corrections. The datum plane was taken as the center of the drive pipe E, Plate 4; and all the heads were calculated from this plane. Water was assumed to rise to the point A in the pressure gauge. This point could not be found very accurately but is not more than one-half inch in error. Since A is one and one-half feet above the datum plane, one and one-half feet were added to the head indicated by the gauge.

When taking cards the cylinder of the indicator was filled with water up to the relief holes C above the piston, from which the water that leaked by the piston overflowed. When drawing the atmospheric line on the card, however, the cylinder was empty, due to the water draining out. Because of this the distance between the atmospheric line and the rest of

the card was shorter in all cases than it should be. It was therefore necessary to correct for the height BC, Plate 4, the ordinate of the card being increased by the pressure due to the column of water BC. This was done by drawing a new atmospheric line at the proper distance below the original one.

When the indicator spring was calibrated the indicator was attached at D, Plate 4, and the various pressures applied were read from the gauge G. Since the indicator was then filled with water to the relief holes at E it was necessary to add the pressure due to the column of water EA to the pressure given by the gauge, in order to obtain the pressure on the indicator piston.

POWER:-

The unit of power may be looked upon as a rectangular prism, whose dimensions are one cubic foot, one pound per square foot, and one minute. The volume would be one foot pound per minute. A volume 33000 times as large would represent one horse power. On Plate 2, Fig. I, is shown such a unit. The volume ABCDHGEF represents one foot pound per minute, and the volume ABKLIGEJ represents one foot pound per hour. The surfaces of such a prism are of three kinds, namely: pressure-volume; time-volume; and pressure-time. The volume representing the power of an engine is seldom a rectangular prism, but is a prism whose section in the pressure-volume plane is of the form given by the indicator card of the engine. Thus if ABCDEF, (Fig. 2), represents the indicator card of a steam engine, and DD' represents one minute, then the volume A B C D E F A'B'C'D'E'F' represents the power of the engine in foot pounds per minute.

In the case of the hydraulic ram it is impracticable to obtain an indicator card in the pressure-volume plane due to the peculiarity of the machine. It is possible, however, to obtain an indicator card in the pressure-time plane, and knowing the volume of water pumped per stroke, determine the rate of doing work, i. e. the power expanded. Thus if ABCDEFG, Fig. 2, represents the indicator card of an hydraulic ram in the pressure-time plane, and AA' represents the volume of water in cubic feet pumped per stroke then the volume A B C D E

F G A'B'C'D'E'F'G' represents the work done per stroke. By integrating the card obtained in the pressure-time plane, the mean pressure in the ram during the time the discharge valve was open can be determined. This multiplied by the time the discharge or check valve was open, in minutes, and by the volume of water pumped, in cubic feet, per stroks, will give the foot pounds of work per stroke in forcing the water through the discharge valve against the discharge head, and friction of the discharge pipe. This work multiplied by the number of strokes per minute and divided by 33000 will give the indicated horse power of the ram.

CARDS:-

The kind of cards obtained from the ram are shown on Plate 3. Both cards were taken during run number nine, second series. Card A was taken with the drum of the indicator rotating at about sixty R.P.M., while card B was taken with the drum making about twenty R.P.M. Card B was taken to obtain the events of a complete cycle of the ram. Card A was taken at a higher speed in order to obtain that portion of the cycle between the closing of the clack valve and its reopening on a larger scale. By obtaining a larger card the time between the various events, and the mean effective pressure, can be determined more accurately.

With reference to the indicator, the operation of the ram is as follows. The clack valve closes during the time represented by AB. (See Fig. 3). The pressure in the ram

increases slightly as the folw of water through the clack,or waste,valve is chocked off. As soon as the clack valve has closed completely, the pressure within the ram rises very rapidly, producing what is known as water hammer.

The oscillations of the water in the supply pipe are rapidly diminished due to the friction of the check valve, and of the supply pipe. When the mean pressure, during these oscillations, falls below the pressure in the air chamber, the water in the air chamber flows back through the check valve until the friction of the passing water closes the valve at C. The pressure below the clack valve then falls, due to the backward movement of the water in the supply, or drive, pipe. At D the clack valve re-opens and the flow of water down the supply pipe begins.

In calculating the indicated horse power from the cards, the mean effective pressure used was that existing during the time the check valve was open. The check valve was assumed to open at G, i.e. when the pressure below the check valve reached the discharge pressure. The valve was assumed to close at the point C, where the line drawn by the indicator ceased to change in direction. This would seem to indicate that the accelerating force due to the discharge pressure had been removed from the water in the supply pipe. Since the discharge valve is hidden within the ram, it would be very difficult to accurately determine its action.

CONCLUSIONS:-

The results show that an indicator may be used to determine the mean pressure within an hydraulic ram, during the time of discharge. If the rate of discharge is known the total energy developed within the ram may be found.

The difference between the pressure indicated in the ram and the pressure in the discharge pipe varies from one-fourth to one pound. The loss in power due to this drop varies from five to seven percent, of that indicated. This shows that the greater part of the waste energy is lost in the drive pipe and clack valve. The loss caused by the clack valve is not very great, however, as the back pressure produced cannot be noticed on the indicator card. The drive pipe is, therefore, responsible for most of the loss in energy.

From the curve traced by the tuning fork on the card, the duration of the various events of the cycle may be obtained very accurately. The average times are given in Table III.

In the test mentioned on page 3, (First application of indicator), the conclusion was arrived at that the number of strokes per minute varied inversely as the length of stroke.

From Table III it is evident that this is very nearly correct. It is, however, evident that this rule applies better to the time the clack valve is open, that is, The time the clack valve is open varies directly with the length of stroke.

(Conclusions Cont.)

The following formulae is found to hold approximately for the time of discharge.

$$p\ t = C\sqrt{S}$$

Where"p"Is the discharge pressure.

"t"is the time of discharge.

"S"the stroke of the clack valve.

and "C"a constant depending upon the adjustment of the weight on the clack valve.

For the particular ram used in this investigation this expression becomes.

$$p,t,=\sqrt{2n}$$

Where "p"is the discharge head in pounds per sq.in.

"t"the time of discharge in seconds.

and "n"the number of turns the nut on the stem of the clack valve is open. Each turn corresponds to I / I8 of an inch.

The efficiency of the ram shown in table II are exceptionally high for a ram of this size. They can only be attributed to the fact that the ram was put in first class condition before begining the te t.

The results in Tables I & II are accurate to within about one percent. Due to difficulty in getting average cards, the results in Tables III & V are not so accurate. This is due to the fact that the ram does not operate quite the same when the indicator is in use, as when it is not.

W. L. Brock.
P. J. Scott.

-: INDICATED POWER OF AN HYDRAULIC RAM :-

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TABLE I.

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NO OF RUN.	WATER IN POUNDS PUMPED.	WASTED.	STROKES PER. MIN.	HEAD IN FT. WATER. SUPPLY.	DISCHARGE.	TURNS OPEN.
I	87.33	228	95.5	6.I	I3.03	I
2	29.34	250	I03.	6.I	24.57	I
3	7.3I	2I4	I05.	6.I	36.I0	I
4	228.86	56I	52	6.I	I3.03	2
5	III.00	636	62	6.I	24.57	2
6	65.26	625	63	6.I	36.I0	2
7	272.40	869	37	6.I	I3.03	3
8	I37.74	I008	4I	6.I	24. 57	3
9	8I.42	959	42.5	6.I	36.I0	3
I0	24.24	974	40	6.I	47.64	3

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-: INDICATED POWER OF AN HYDRAULIC RAM :-

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-: TABLE II :-

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RUN NO	WATER IN POUNDS OF.PUMPED.	WASTED.	STROKES PER.MIN.	HEAD IN FT. SUPPLY.	DISCHARGE.	WATER EFFICIENCIES $\frac{wh}{H(W+w)}$	$\frac{w(h-H)}{WH}$
I	87.33	228	95.5	6.I	I3.03	59.2	43.5
2	29.34	250	I08	6.I	24.57	42.3	35.5
3	7.3I	2I4	I05	6.I	36.I0	I9.5	I6.8
4	228.86	56I	52	6.I	I3.03	6I.9	46.3
5	III.00	636	62	6.I	24.57	59.8	52.9
6	65.26	625	63	6.I	36.I0	55.9	5I.4
7	272.40	869	37	6.I	I3.03	5I.0	35.6
8	I37.74	I008	4I	6.I	24.57	48.3	4I.4
9	8I.42	959	42.5	6.I	36.I0	46.3	50.3
I0	24.24	974	40	6.I	47.64	I9.0	I6.9

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-: INDICATED POWER OF AN HYDRAULIC RAM :-

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TABLE III.

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NO OF RUN.	TIME OF DISCHARGE IN SECONDS.	TIME OF CYCLE IN SECONDS.	TIME CLACK VALVE IS OPEN IN SECONDS.	MAXIMUM PRESSURE DURING DISCHARGE.
I	0.246	0.625	0.35o	5I
2	0.I00	0.559	0.4I2	I7
3	0.072	0.57I	0.474	2I
4	0.402	I.I63	0.727	I6
5	0.I85	0.979	0.772	23
6	0.I2I	0.954	0.808	32
7	0.508	I.679	I.I42	I7
8	0.235	I.466	I.I97	24
9	0.I56	I.435	I.255	33
I0	0.I34	I.503	I.340	3o

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-: INDICATED POWER OF AN HYDRAULIC RAM :-

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WATER PER STROKE

TABLE IV.

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NO OF RUN.	WATER PUMPED POUNDS.	WATER WASTED POUNDS.	WATER PUMPED CU. FT.	WATER WASTED CU. FT.
I	.06096	.I59I	.000977	.00254
2	.0I8II	.I543	.000290	.00247
3	.00464	.I3586	.000074	.002I7
4	.2934I	.7I92	.00470I	.0II52
5	.II935	.6838	.00I9I2	.0I095
6	.06906	.66I3	.00II06	.0I0596
7	.4908I	I.5657	.007864	.02508
8	.22396	I.6390	.003588	.02626
9	.I277I	I.5043	.002046	.024II
I0	.04040	I.6233	.000647	.0260I

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-: INDICATED POWER OF AN HYDRAULIC RAM :-

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TABLE V

DATA FROM CARDS

NO OF RUN.	AREA OF CARD.	LENGTH OF C A R D.	M.E.P.	M.E.P. CORRECTED.	DISCHARGE HEAD IN POUNDS.
I	0.578	2.75	5.64	5.86	5.65
2	0.447	I.03	II.00	II.22	I0.65
3	0.455	0.76	I6.05	I6.27	I5.65
4	0.870	3.76	6.20	6.42	5.65
5	0.66	I.60	II.05	II.27	I0.65
6	0.65	I.08	I6.I3	I6.35	I5.65
7	0.825	3.92	5.64	5.86	5.65
8	0.76	I.68	I0.78	II.00	I0.65
9	I.030	I.68	I6.43	I6.65	I5.65
I0	I.I07	I.44	20.60	20.82	20.65

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Fig. 1a

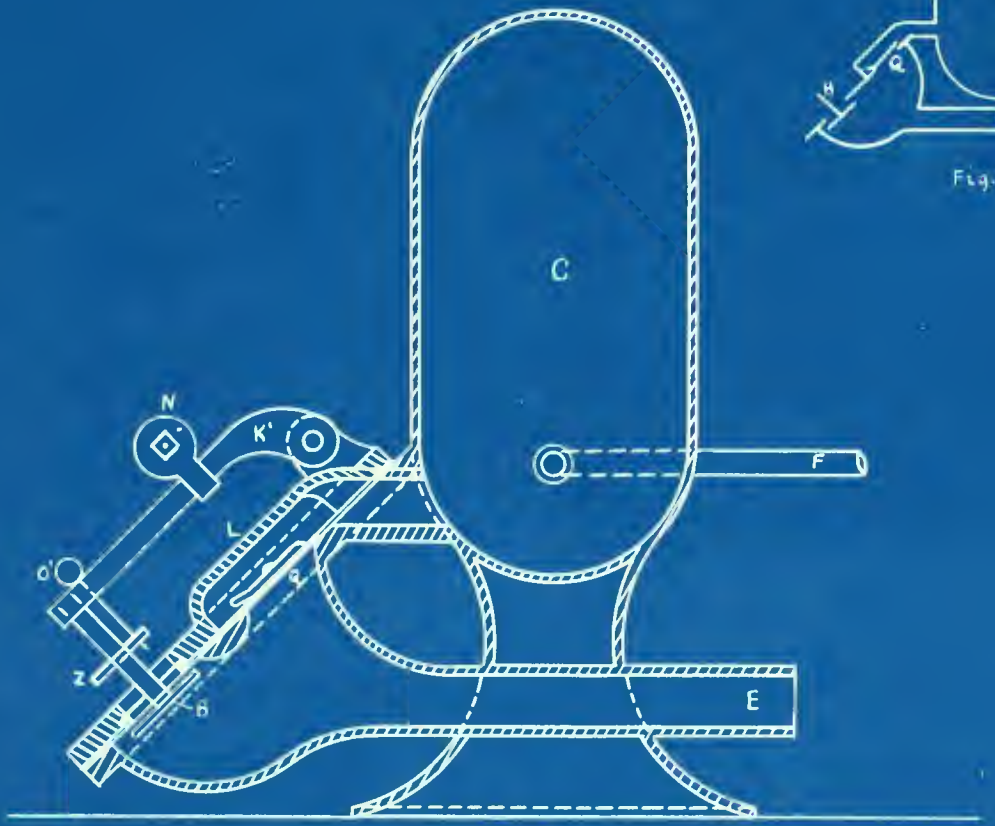

Fig. 1

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Plate 1

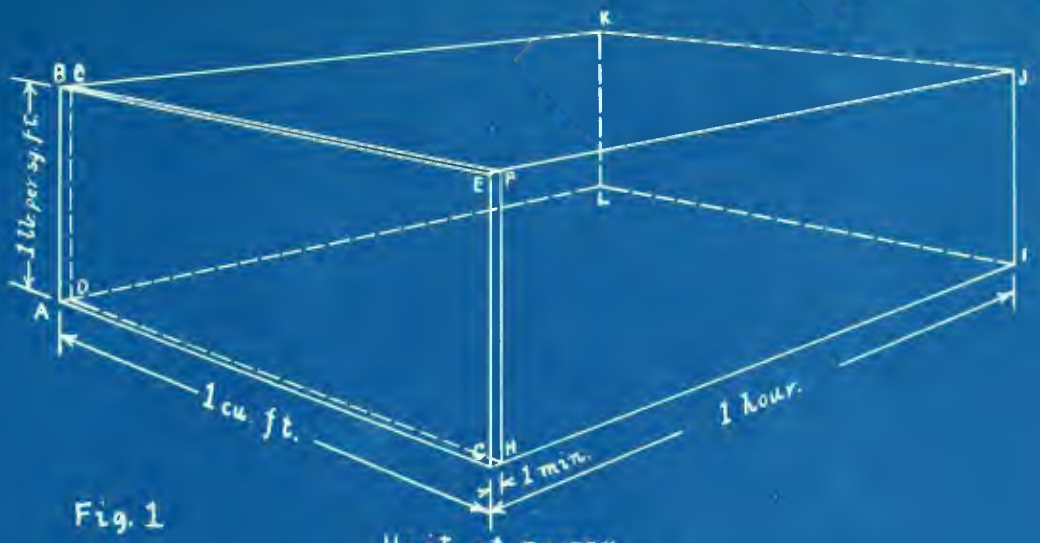


Fig. 1

Unit of power

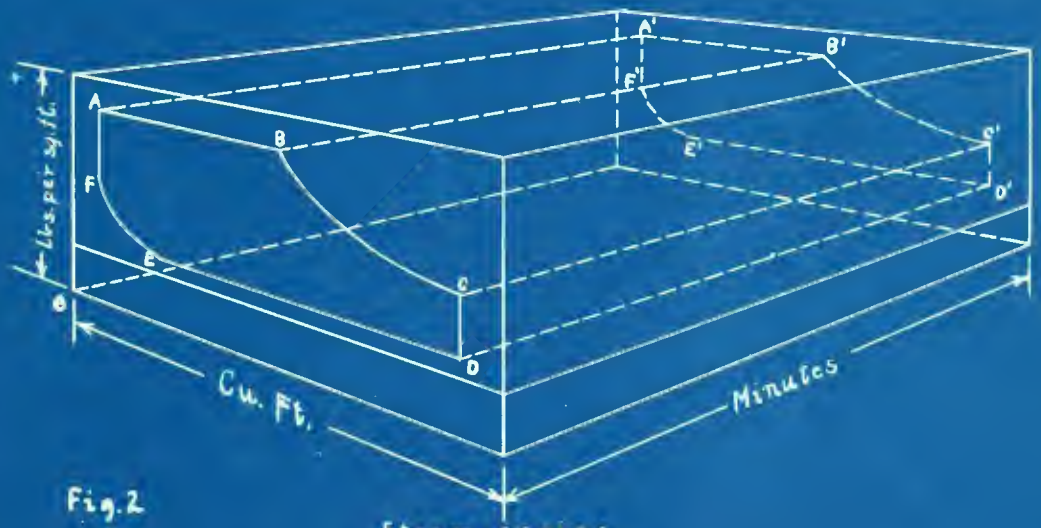


Fig. 2

Steam engine.

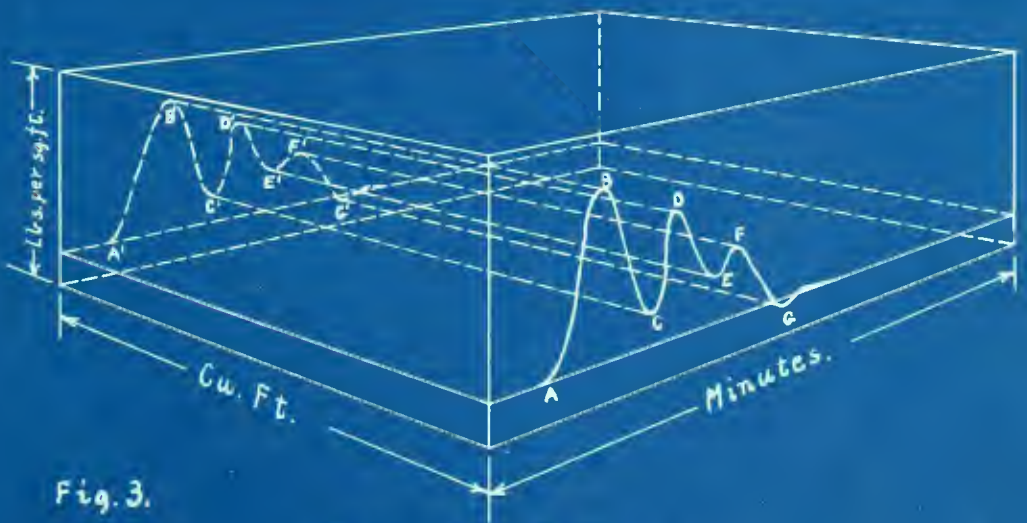
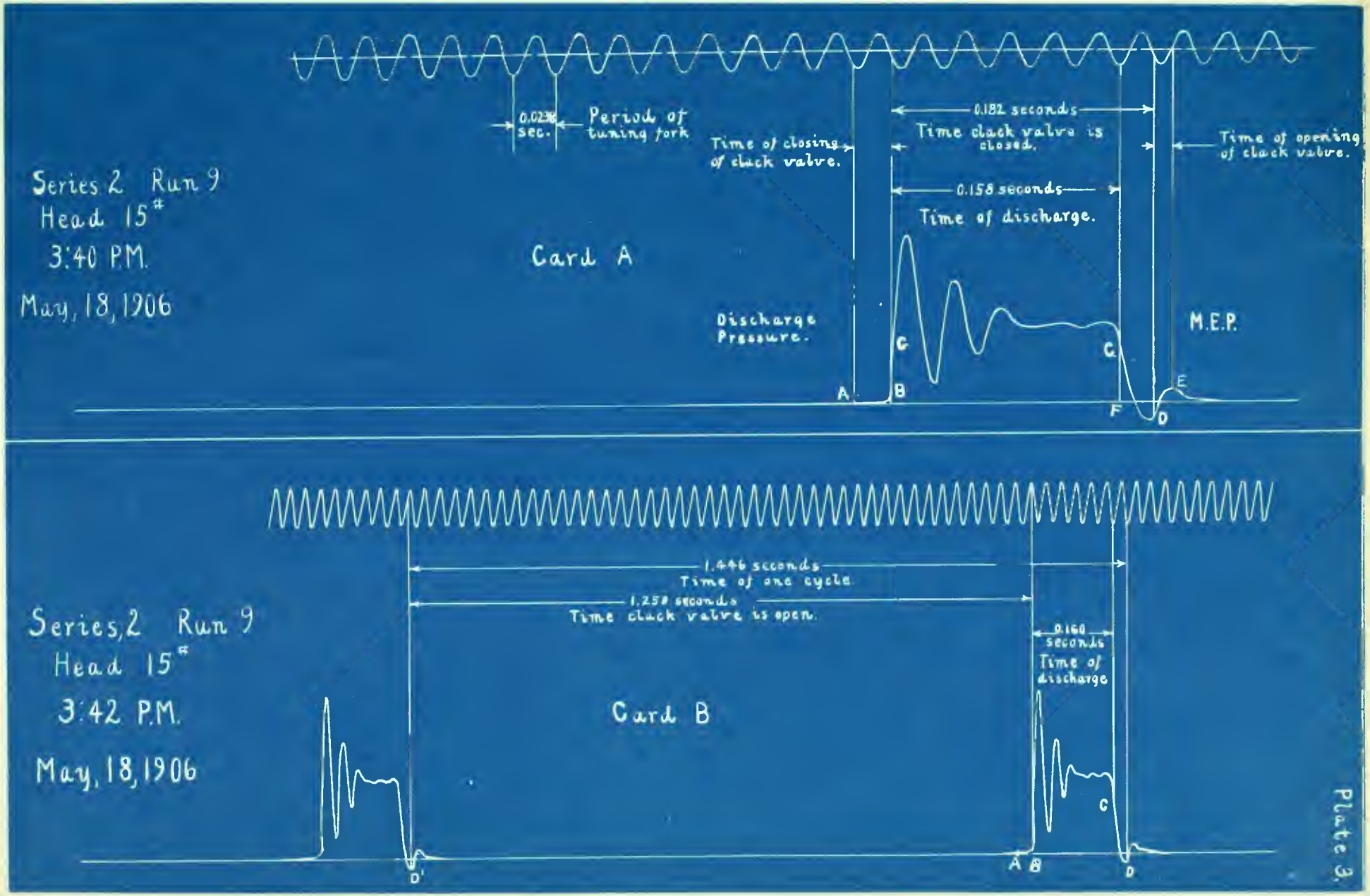


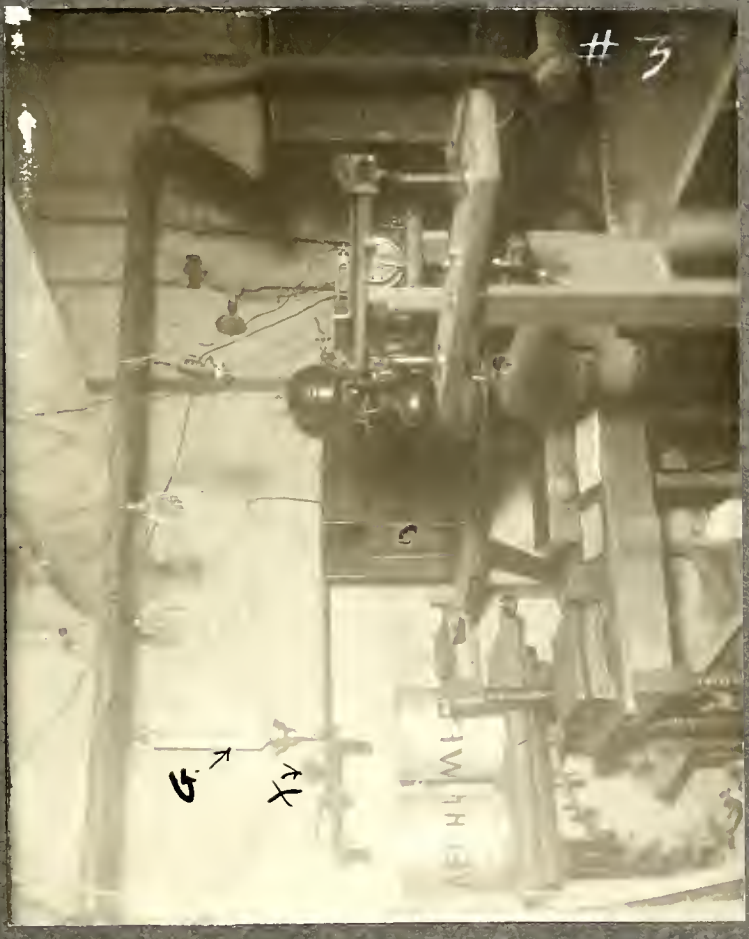
Fig. 3.

Hydraulic Ram.


0.0238 sec.
Period of tuning fork
Time of closing of clack valve.
0.182 seconds
Time clack valve is closed.
Time of opening of clack valve.
0.158 seconds
Time of discharge.
Series 2 Run 9
Head 15#
3:40 P.M.
May, 18, 1906
Card A
Discharge Pressure.
M.E.P.
A
B
C
C
D
E
F
1.446 seconds
Time of one cycle
1.258 seconds
Time clack valve is open.
0.160 seconds
Time of discharge
Series 2 Run 9
Head 15#
3:42 P.M.
May, 18, 1906
Card B
D'
A
B
C
D
Plate 3.

#2

#1


#3

4

#7

#5.

#6